Renewable and Sustainable Energy Reviews 14 (2010) 500–505

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Returns on investment in electricity producing photovoltaic systems under de-escalating feed-in tariffs: The case of Greece

Svetoslav Danchev [a,b], George Maniatis [a,b], Aggelos Tsakanikas [a,*]

[a] Foundation for Economic & Industrial Research (IOBE), 11 Tsami Karatassou Str., Athens 117 42, Greece
[b] National and Kapodistrian University of Athens, Greece

ARTICLE INFO

Article history:
Received 26 June 2009
Accepted 10 August 2009

Keywords:
Photovoltaic
Pricing
Policy design
Investment
Learning

ABSTRACT

Under the threat of ballooning energy bills, the Greek legal framework supporting the electricity producing photovoltaic systems (PVS) changed in January 2009 from a fixed to a de-escalating feed-in tariff schedule. In this paper we investigate the internal rate of return (IRR) on investing in PVS under the new regulatory environment. We find that the new scheme favours strongly the early entry in the market. Unless there is a significant decrease in the equipment cost over the next decade, entering the market from 2015 onwards will be prohibitive. The bias of the current policy design towards early entry in a rapidly developing set of technologies entails the risk of a lock-up with sub-optimal technological option. This outlines the importance for policy design of linking the rate of feed-in-tariff de-escalation to more realistic expectations regarding the technology learning curve.

Contents

1. Introduction

The European Union, in its attempt to lead the global climate change mitigation campaign and in order to enhance its energy security, has set binding targets on the penetration of the renewable energy sources (RES) in the energy mix until 2020 [1,2]. Greece is obliged to ensure that 18% of the final energy consumption in 2020 comes from RES. This implies that Greece has to restructure radically its existing energy mix. The need for the immediate implementation of solutions that will provide incentives for developing the full spectrum of RES technologies that have an increased potential in Greece (on-shore wind, solar, hydro, geothermal, etc.) is intensifying.

The photovoltaic systems for producing electricity (PVS) are considered to be amongst the technologies that will contribute significantly to the achievement of the RES targets in Greece due to the favourable climatic conditions [3]. The PVS technology, however, is still commercially immature compared both with the conventional electricity producing technologies and with other RES technologies, such as on-shore wind turbines. The relatively low level of the electricity prices in Greece magnifies the problem. The PVS cannot be competitive enough in the Greek wholesale market without generous incentive schemes, at least for the time being.

There is a strong rationale to subsidise the penetration of infant technologies, such as PVS, in order to utilise their significant cost reduction potential. In addition, the PVS substitute technologies with high negative external costs. It is important, however, to avoid the lock-up with a particular photovoltaic technological option that might turn out to be inferior ex-post [4]. Such a risk is

* Corresponding author. Tel.: +30 210 9211265; fax: +30 210 9233977.
E-mail address: atsakanikas@iobe.gr (A. Tsakanikas).

1364-0321/$ – see front matter
doi:10.1016/j.rser.2009.08.008

Table 1
The 2006 feed-in tariffs schedule (€/MWh).

Energy source	Interconnected system	Non-interconnected islands
Small PV (≤100 kWe)	450	500
Large PV (>100 kWe)	400	450
Small non-PV solar (≤5 MWe)	250	270
Large non-PV solar (>5 MWe)	230	250
Off-shore wind	90	90
Other RES (on-shore wind, small hydro, geothermal, biomass, etc.)	73	84.6

Source: [5].

introduced by incentive schemes that are biased towards early entrants.

The incentive scheme that was established in Greece in 2006 included, apart from priority in the dispatch and an investment subsidy, a feed-in tariff for purchasing the electricity generated by PVS [5].[1] The PVS feed-in tariffs were set at levels 5–6 times higher than the corresponding on-shore wind and hydro feed-in tariffs (Table 1). In order to make the grid restrictions explicit, but also to control the overall cost for the consumers, the national RES implementation programme set an upper limit on the PVS capacity per administrative region.

The surge of applications for licences (for PVS with capacity above 150 kW) and licence exemptions (for PVS with capacity between 2 and 150 kW) exceeded by far the limits set by the programme (Fig. 1). The licensing authorities were not in a position to cope with the thousands of applications that were received (Table 2). The programme limits (in terms of granted licences and exemptions, but not installed capacity) were quickly reached and a parallel 'market' for licences emerged. Providing strong price incentives, on one hand, and setting quantity restrictions on the other was indeed a rather odd arrangement. The paradox situation of lagging behind on the path to meeting the RES targets and refusing to grant licences to thousands MW of PVS capacity led to the need for a radical restructuring of the incentive scheme.

The deficiency of the 2006 incentive scheme, coupled with the administrative burden of the rather bureaucratic licensing procedure, explains the still low level of PVS penetration in Greece, compared with other European Union countries with similar climate conditions. By the end of 2008, the total installed photovoltaic capacity in Greece was equal to only 9.3 MW, out of which 8.7 MW were connected to the grid. This represents a mere 0.2% of the total PVS capacity in the EU-27 group, which amounts to 4592 MW. Only in 2008 Spain added 2080 MW, Italy's capacity increased by 127 MW, while Portugal acquired 36 MW of total new PVS capacity [7].

In the light of these new developments a new scheme was voted for in January 2009 [8]. The capacity limits were scrapped. Granting licences to all applicants would have led to a large increase in the retail price of electricity and to a fuel mix that would not have been optimal even if all external environmental costs were taken into account.[2] In order to moderate the burden on the final consumer from the PVS programme, the feed-in tariff in Greece was set to gradually de-escalate.

The next section of this paper contains a description of the new legal framework in somewhat more detail. We proceed with an outline of the methodology used in order to evaluate the attractiveness to invest in PVS. The results vary according to the geographical position of the PVS and its size, which is the topic of the first results section. We then move to check the sensitivity of our results to changes in the values of stochastic and policy parameters. We conclude with the dynamic extension of the analysis, which evaluates the tariff de-escalation effect on entry.

[1] For an in-depth review of the incentive scheme prior to 2006, see [6].

[2] For some estimates on the total burden from high feed-in tariff regimes for PVS in the case of Germany, see [9].

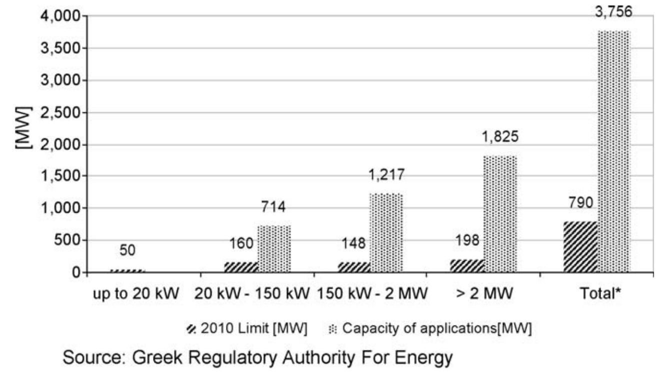

Fig. 1. Capacity in licence applications (18/3/2008) and the limit set in the old legal framework.
Source: Greek Regulatory Authority For Energy.
*The total includes the capacity limits for the islands in the interconnected system and the non-interconnected islands, where the limits were not broken down by PVS size.

Table 2
Number of PVS applications and average capacity on 18/3/2008[a].

PV capacity	Number of applications	Average capacity [in MW]
20–150 kW	6647	0.11
150 kW–2 MW	1004	1.21
>2 MW	296	6.17
Total	7947	0.47

Source: Greek Regulatory Authority For Energy.
[a] From this date onwards Regulatory Authority of Energy ceased to receive applications for granting electricity generation licences for PVS installations.

2. The 2009 PVS incentive scheme

As we mentioned earlier, the main changes from the 2006 PVS investment support scheme include abandoning the capacity limits while also adopting de-escalation of the feed-in tariff. Each PVS operator is rewarded with the feed-in tariff that is in force at the time of the signing of the electricity supply contract with the grid operator. The contract has a 20 years duration. In case the PVS operator is not in the position to start test operation (or connect to the grid if test operation is not envisaged) within 18 months for PVS with capacity less than 10 MW or 36 months for PVS with capacity higher than 10 MW, then he/she will be rewarded with the feed-in tariff that will be valid at the start of the operation.

The tariffs are initially set at 400, 450 or 500 €/MWh depending on the PVS's size (larger or smaller than 100 kW) and location (interconnected system or non-interconnected islands). Starting from August 2010, the tariffs de-escalate every 6 months to reach 260.97–326.22 €/MWh for the period August–December 2014 (see Table 3). This amounts to an accumulated reduction of 35% over the period of 6 years or 6.9% compounded annual reduction rate. From January of 2015, the feed-in tariffs will be set to the previous year's average price in the wholesale electricity market plus a premium that varies between 30% and 50% depending on the PVS's size and location. The PVS with capacity lower than 100 kW and those that are installed in the non-interconnected islands are paid higher feed-in tariffs both before and after January 2015.

The feed-in tariff schedule is updated each year, taking into consideration the inflation rate. The compensation is not full, however, but amounts only to 25% of inflation. The rationale of the

Table 3
The 2009 PVS feed-in tariff de-escalation (€/MWh).

Date	Interconnected system		Non-inteconnected islands	
	>100 kW	≤100 kW	>100 kW	≤100 kW
February-09	400.00	450.00	450.00	500.00
August-09	400.00	450.00	450.00	500.00
February-10	400.00	450.00	450.00	500.00
August-10	392.04	441.05	441.05	490.05
February-11	372.83	419.43	419.43	466.03
August-11	351.01	394.88	394.88	438.76
February-12	333.81	375.53	375.53	417.26
August-12	314.27	353.56	353.56	392.84
February-13	298.87	336.23	336.23	373.59
August-13	281.38	316.55	316.55	351.72
February-14	268.94	302.56	302.56	336.18
August-14	260.97	293.59	293.59	326.22
For each year *n* from 2015 onwards	1.3 × Average SMP_{n-1}	1.4 × Average SMP_{n-1}	1.4 × Average SMP_{n-1}	1.5 × Average SMP_{n-1}

Source: [8].
SMP: System Marginal Price.

*x*CPI rule is that the less than full compensation provides incentives for constantly improving the efficiency of the subsidised unit through innovation, learning, and so on. In the case of PVS, where the disproportionately higher percentage of the cost to the PVS operator comes from the investment expenditure, made prior to the beginning of operation, the adoption of this rule is not adequately justified. Setting the compensation parameter at such low levels actually implies a second-order de-escalation effect.

The de-escalating of the feed-in tariff alleviates the burden on the consumers who have to provide the funds for the subsidy through a specially designed RES tax. It also eliminates potential market power problems which may arise from the concentration in the global photovoltaics industry. However, if the technological progress envisaged in the policy design is not as quick as expected, the penetration of PVS might abruptly cease when the feed-in tariffs fall below the technology's levelised cost. Hence, the current legal framework contains a provision that the authorities may change the feed-in tariff de-escalation path depending on the technology's penetration levels and the consumer cost. Our results indicate that the enactment of this provision is very likely, taking into consideration the current expectations on the future technological and price developments.

3. Methodology for calculating the rate of return on the investment

The evaluation of the investment in the production of electricity with PVS under the new support scheme is performed by calculating the internal rate of return (IRR) of the investment. A popular investment rule states that if the IRR of an investment A is higher than that of other feasible alternative investments, where the rates are risk-adjusted to make them comparable, the investment A is considered as attractive. However, there are notable exceptions to this rule [10]. In the case of PVS, their interaction with other technologies in electricity generation portfolio might reduce the overall portfolio risk at a cost worth paying, thus making the investment in a PVS worthwhile even if on its own it has low IRR [11]. Even though in practice the IRR rule is not always applied, the IRR remains an important indicator of an investment's attractiveness.

Table 4
Net cash flows calculations.

Cash flow *C* at time *t* (calculation and assumptions)
– Initial investment expenditure
Corresponds to the equity capital that is invested, which we assume covers 25% of the total investment cost. The rest is covered by a loan and an investment subsidy. In our calculations we assume that:
(a) The investors secure the maximum subsidy envisaged within their administrative region.
(b) For the remainder of the investment cost that is not covered by the equity capital and the subsidy the investors secure a loan with 10 years duration and 7% interest rate.
(c) The investment cost gradually falls starting from about 5700 €/kW [7].
+ Revenue from electricity sales
Calculated as the product of the feed-in tariff and the generated electricity. The generated electricity was estimated for each administrative region using the PVGIS database [13,14], taking the weighted average of the annual generation of a fixed position PVS (2/3 weight) and a 2-axis tracking system (1/3 weight). The PV technology is crystalline silicon with 14% system losses, optimum slope and optimum azimuth. The calculations incorporate:
(a) Increase in the feed-in tariff by 25% of last year's inflation rate.
(b) Loss in the productivity of the PVS by 0.8% annually.
– Loan capital repayment
Includes the instalments of the loan capital, paid every 6 months.
– Interest payments
Includes the interest payments for the loan, paid every 6 months.
– Operating and maintenance cost
Assumed to be equal to 1% of the total investment cost per annum.
Depreciation expense
Assumed to be equal to 5% of the total investment cost per annum. This implies that the investment is fully depreciated over the PVS's operation period. The depreciation expense is subtracted to calculate the corporate tax, but is not subtracted in the calculation of the net cash flow.
– Corporate tax
Levied at the total revenues minus the interest payments, the depreciation expense and the operating and maintenance cost. We assume that the corporate tax rate remains at 25% for the duration of the PVS's operation.
= Net cash flow
All the cash flows are calculated at constant €2008 prices under the assumption that the price level rises at the rate of 2% per annum.

As a reminder, IRR of an investment with cash flows C_t that lasts for n periods is calculated using formula (1):

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+IRR)^t} = 0 \qquad (1)$$

For the purposes of this study we calculated the net cash flows for an investment in PVS that lasts for 20 years, taking into account the data and the assumptions presented in Table 4.

4. Results per PVS category and administrative region

The internal rate of return for an investment in PVS is expected to differ across the various Greek regions. This is due to differences in the feed-in tariff in the interconnected system and the non-interconnected islands, in the maximum level of investment cost subsidy and in the climatic conditions (average temperature and solar irradiation) across the regions. Those regions with more intense solar irradiation, lower average temperature and the non-interconnected islands are expected to offer higher internal rates of return, *ceteris paribus*.

Indeed, the results from the IRR calculation presented in Table 5 confirm these hypotheses. Higher IRRs are reported in the islands in the Northern and Southern Aegean Sea and in Crete, which are non-interconnected islands. The relatively low scores for the Attica region, where the potential for electricity production from PVS is higher than in many other regions in the interconnected system, are explained by the fact that a relatively smaller percentage of the investment cost is subsidised. These results stress the importance of the government subsidy on the initial capital expenditure for the viability of the PVS investment, even in the case when the feed-in tariffs are exceptionally high.

Furthermore, the IRR appears to be higher for smaller PVS, as expected, given the different feed-in tariff that they enjoy. We should not forget, however, that in market terms the investment cost per kW for smaller PVS is expected to be higher, due to increasing returns to scale. This implies that the difference in IRR according to size is probably overestimated here.

It should also be stressed that the reference date for these calculations is January 2009. This means that we estimate the IRR for investments that could be contracted at that date. The calculations that take into account the de-escalation of the feed-in tariffs are presented in the following sections of this paper.

The IRR calculations here are significantly higher than those reported in [12] for France, Italy, Germany and Spain. The difference comes mainly from the fact that in Greece a substantial part of the initial investment cost can be subsidised. Our results also incorporate a positive effect from leveraging the specific investment with a bank loan, whose interest is lower than the overall rate of return on the investment.

Table 5
Internal rate of return per capacity category and geographical region/zone.

Region/zone	Internal rate of return	
	>100 kW	≤100 kW
North Aegean	21.9%	30.5%
South Aegean	19.1%	27.6%
Crete	17.8%	26.1%
Peloponnese	16.8%	25.1%
West Greece	15.0%	22.9%
Epirus	14.7%	22.6%
East Macedonia and Thrace	14.1%	21.9%
West Macedonia	12.7%	20.4%
Central Greece	12.1%	19.6%
Central Macedonia	11.5%	19.0%
Thessaly	10.9%	18.3%
Ionian Islands	10.9%	18.2%
Attica	10.2%	17.4%
Interconnected system	*13.5%*	*21.2%*
Non-interconnected islands	*20.2%*	*28.7%*

5. Sensitivity analysis

The above calculations are based on a number of exogenous parameters whose values are hypothetical or subjected to policy changes. To check the robustness of our results we performed a sensitivity analysis to changes in the exogenous parameters and the policy levers. For each parameter, we calculated the IRR for values of the parameter lower and higher than 25% compared with its reference point. The results are shown in Table 6.

The results are highly sensitive to three of the exogenous parameters, that is, the investment cost, the investment subsidy and the annual electricity generation per kW of installed PVS capacity. An investment cost lower with 25% than the reference value would lead to an IRR higher with 10.3 points, while 25% higher investment cost would be associated with a drop in the IRR by 6.1 points. Similar decrease in the IRR would be experienced if instead of securing the maximum subsidy, the investors manage to secure only 75% of that amount. Even more intense is the drop in the IRR from a 25% decrease in the annual generation. A 25% change in the remaining parameters does not lead to a change in the IRR higher than 1.1 points.

The sensitivity analysis stresses the importance of keeping the investment cost (net of the subsidy) as low as possible for the profitability of a PVS investment. It is also important to design the system at the most optimal conditions in order to avoid shadowing and related issues, leading thus to achieve maximal annual production [15]. The sensitivity analysis also provides added security to the investors since moderate changes in policy levers, macroeconomic conditions and terms of funding have rather limited effect on the investment return.

Table 6
Sensitivity of the IRR calculations for a PVS in the interconnected system with capacity less than 100 kW and contract date January 2009.

Parameter name	Units	−25%		Reference case		+25%	
		Value	IRR	Value	IRR	Value	IRR
Investment cost	€'08/kW	*4278*	31.5%	*5704*	21.2%	*7129*	15.1%
Investment subsidy	%	*41%*	15.1%	*55%*	21.2%		
Loan interest rate	%	*5.3%*	21.8%	*7.0%*	21.2%	*8.8%*	20.6%
Loan duration	years	*7.5*	20.4%	*10*	21.2%	*12.5*	22.3%
Inflation rate	%	*1.5%*	21.7%	*2.0%*	21.2%	*2.5%*	20.8%
Operating expenses	% of i.c.	*0.75%*	22.0%	*1.0%*	21.2%	*1.25%*	20.4%
Annual production	kWh/kW	*995*	13.6%	*1327*	21.2%	*1659*	28.9%
Productivity loss	%	*0.6%*	21.4%	*0.8%*	21.2%	*1.0%*	20.9%
xCPI rule	%	*19%*	21.0%	*25%*	21.2%	*31%*	21.3%
Income tax	%	*19%*	21.9%	*25%*	21.2%	*31%*	20.5%

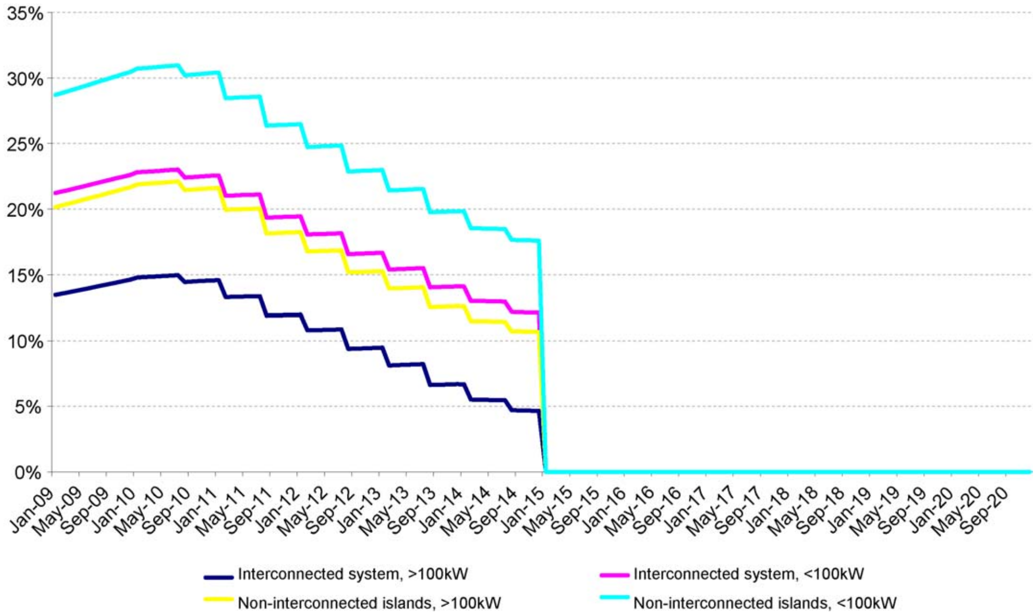

Fig. 2. Evolution of the internal rate of return per zone and PVS size.

6. The feed-in tariff de-escalation and IRR's evolution

The PVS operators lock for 20 years the feed-in tariff that is in force at the date when the contract between them and the grid operator is signed. The evolution of the internal rate of return over the time scale (contract dates) per zone and PVS size is presented in Fig. 2. For the evolution of the PVS investment cost we use the results in [16], which are calculated using a technological learning curve model, using the base scenario for PVS global penetration. The calculations imply that the investment cost drops on average of 2.5% each year. On the revenue side, we use the predictions on the evolution of the average electricity wholesale price from [17] for the calculations that extend beyond 2014.

The feed-in tariff de-escalation that is implemented under the new support scheme implies decreasing rate of return, since the investment cost decreases at a lower rate compared to the rate of feed-in tariff de-escalation, provided the remaining parameters remain fixed. From January 2015 onwards, when the feed-in tariff is linked to the electricity wholesale price plus a mark-up of 30–50%, the internal rate of return cannot be calculated as there is no positive rate that can prevent the net present value from taking negative values. In other words, after January 2015 the present value of the future cash inflows is not adequate to cover the initial cash outflow under any discount rate. Thus, investment in this market after January 2015 – provided that the investment cost and electricity price projections follow our predictions – will no longer be attractive (unless the investment takes place within a broader portfolio strategy). But even before 2015 the internal rate of return – especially for larger PVS in the interconnected system – might not surpass an acceptable opportunity cost of capital, making the investment unprofitable.

The required reduction in the investment cost that will maintain the IRR at reasonable levels (e.g. above 10%) is shown in Fig. 3. The investment cost should reach levels 65–75% lower than projected in RE-Xpansion's base case scenario in order to keep the investment profitable. Technological progress leaps and substantial economies of scale are required in order to achieve such reductions in the investment cost.

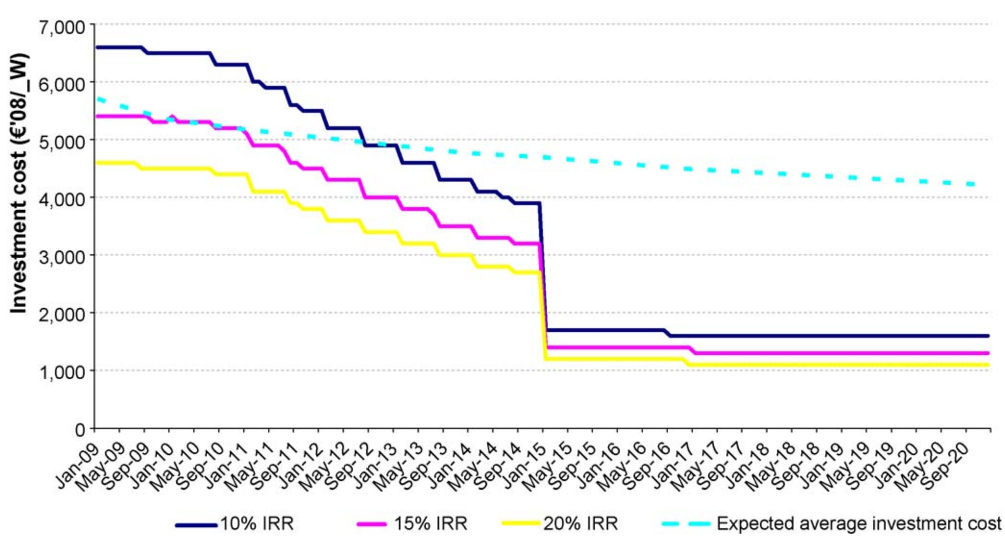

Fig. 3. Evolution of the investment cost for given internal rate of return (PVS in the interconnected system with capacity higher than 100 kW).

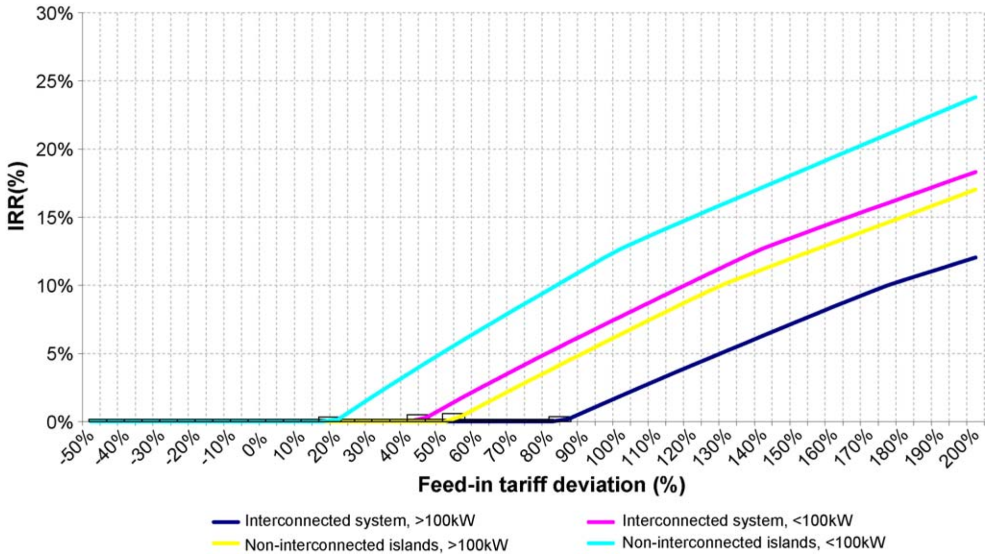

Fig. 4. IRR and feed-in tariff deviation for PVS with contract date December 2020.

This conclusion depends crucially on the predictions for the energy prices that will prevail after 2014. As shown in Fig. 4, the feed-in tariffs should be higher by 85–175% (depending on PVS's location and size) in 2020 than the current projections so that the PVS investment secures a 10% IRR. Unless the real energy prices increase dramatically, the investment cost shrinks substantially or the current investment scheme is radically modified, the investment in new PVS capacity will most probably be discontinued in Greece after 2014.

7. Concluding remarks

Even though the feed-in tariff for PVS is significantly higher than the current electricity wholesale price, the high rates of return to PVS investments are not guaranteed. The most important parameter that affects the attractiveness of the investment is the PVS location. The internal rates of return differ significantly depending on the subsidies provided for covering the initial investment across the different administrative regions, together with the geographical latitude of the location and the possibility of its interconnection with the national grid.

The evolution of the return rates crucially depends on the reduction rates of the PVS purchasing cost, which is difficult to predict, as the demand for photovoltaic installations is heavily influenced by support policies that are not coordinated at a global level. The global demand for PVS is expected to grow at extremely high rates (43% CAGR for the period 2007–2012 [18]). It remains to be seen whether the PVS supply chain and producing capacity will be able to keep pace so that the PVS prices fall as quickly as predicted, taking advantage of the increasing economies of scale. In case the investment cost does not fall drastically, entry into the Greek market from 2015 and onwards will not be profitable. The support scheme will most probably have to change if the PVS technology is to continue its expansion after 2015, contributing to the national targets for RES penetration in the Greek energy mix.

References

[1] European Commission, Communication from the Commission: 20-20 by 2020, Europe's climate change opportunity [COM (2008) 30], Brussels; 2008.
[2] European Commission, Text of the Directive on the promotion of the use of energy from renewable sources as adopted by the European Parliament on 17 December 2008 (provisional edition), Brussels; 2008.
[3] Tsoutsos T, Papadopoulou E, Katsiri A, Papadopoulos AM. Supporting schemes for renewable energy sources and their impact on reducing the emissions of greenhouse gases in Greece. Renewable and Sustainable Energy Reviews 2008;12:1767–88.
[4] Sandén BA. The economic and institutional rationale of PV subsidies. Solar Energy 2005;78:137–46.
[5] Hellenic Republic. Law 3468/2006, Electricity generation form RES, combined heat and power generation and other provisions. FEK 129, June 27th 2006.
[6] Tsoutsos T, Mavrogiannis I, Karapanagiotis N, Tselepis S, Agoris D. An analysis of the Greek photovoltaic market. Renewable and Sustainable Energy Reviews 2004;8:49–72.
[7] EurObserv'ER. Photovoltaic barometer. Le Journal du Photovoltaïque 2009;1:72–103.
[8] Hellenic Republic. Law 3734/2009, Promotion of combined generation of two or more energy sources, regulations regarding Mesohora's hydroelectric plant and other provisions. FEK 8, January 28th 2009.
[9] Frondel M, Ritter N, Schmidt CM. Germany's solar cell promotion: dark clouds on the horizon. Energy Policy 2008;36(11):4198–204.
[10] Brealey RA, Myers SC. Principles of corporate finance, 5th ed., McGraw-Hill; 1996.
[11] Albrecht J. The future role of photovoltaics: a learning curve versus portfolio perspective. Energy Policy 2007;35:2296–304.
[12] Campoccia A, Dusonchet L, Telaretti E, Zizzo G. Comparative analysis of different supporting measures for the production of electrical energy by solar PV and Wind systems: four representative European cases. Solar Energy 2009;83(3):287–97.
[13] European Commission, Photovoltaic Geographical Information System (PVGIS).
[14] Šúri M, Huld T, Dunlop E, Ossenbrink H. Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy 2007;81:1295–305.
[15] Barbose G, Wiser R, Bolinger M. Designing PV incentive programs to promote performance: a review of current practice in the US. Renewable and Sustainable Energy Reviews 2008;12:960–98.
[16] Rexpansion, Electricity from Renewable Energy Sources in EU15 Countries: Future Potentials & Costs; 2005.
[17] Maniatis G, Danchev S, Patokos A, Mountrouidis S. Renewable energy sources as energy and business choice. Foundation for Economic and Industrial Research; 2008 [in Greek].
[18] Mints P. PV demand: 2007 and beyond. Renewable Energy Focus 2008;9(4):60–2.